INJURY BIOMECHANICS RESEARCH
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STUDY OF FOREARM - AIR BAG INTERACTION USING THE RESEARCH ARM INJURY DEVICE (RAID)

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ABSTRACT

Based on field studies conducted by Taylor [1], a mechanical device called the Research Arm Injury Device (RAID) was developed to assess forearm-air bag interaction and the relative aggressivity of different air bag systems.

Results from static air bag deployment tests with the RAID suggested that the RAID was able to clearly distinguish between the aggressive and less-aggressive air bags. Maximum moments ranging between 100 Nm and 650 Nm, and hand fling velocity ranging between 30 and 120 km/h were measured on the RAID in these tests. In general, the aggressive air bags imparted a maximum moment on the RAID above 300 Nm and a hand fling velocity above 70 km/h.

Two factors were identified as critical to the test setup. The first was the orientation of the arm with respect to the air bag module. The second was the distance of the arm from the plane of the air bag module face. The maximum moment and fling velocity increased when the initial distance between the RAID and the air bag module was reduced.

INTRODUCTION

This paper presents the second phase of a research effort to get a better understanding of the problem related to upper extremity trauma induced by the air bag. The first phase of the research effort has already been presented at the Twenty-Third International Workshop on Human Subjects for Biomechanical Research [1].

In the first phase of the research effort, an examination of the NASS database suggested that the incidence of upper extremity injury was four times greater for drivers where an air bag deployed while restrained by a 3-point belt than those were were restrained simply by a 3 point belt [1]. Detailed review of accident cases from various data bases suggested three most common arm injury mechanisms related to the deploying air bag. It was also noted from the detailed accident reviews that upper extremity trauma due to air bag deployment was mainly at the distal forearm and was more prevelant among women of small stature.

THE RESEARCH ARM INJURY DEVICE

The detailed study of NASS cases suggested two distinct types of upper extremity injury mechanisms related to air bag deployment [1]. The first type of mechanism is where the arm is directly contacted by the deploying bag and/or module flap cover flap. This results in high bending moments on the arm causing injury in some instances. The second type of mechanism involves the arm being flung away at a high velocity and impacts some portion of the vehicle interior or the driver body. The objective in this phase of the research effort was to develop a simple research tool to evaluate the relative severity of air bags from different manufacturers taking into consideration these established modes of upper extremity trauma.

The Research Arm Injury Device or RAID was developed as an investigative tool to study arm-air bag interactions. The RAID is made from an aluminum tube with double pivot attachment to allow motion along two axes. It has the approximate cross-sectional properties and weight (1.6 kg) of a human forearm. A small mass (0.5 kg) is attached to the free end of the RAID to simulate the hand. The length of the RAID was extended to 46 cm to protect the pivot attachments from the deploying air bag. The RAID instrumentation includes five stations of diametrically opposed strain gages to measure moments along two axes. In addition, the pivot rotations are measured by two angular potentiometers and the accelerations are measured by a triaxial accelerometer block attached approximately at mid-length of the RAID. The RAID is covered with 2 cm of foam and rubber skin similar to that on the Hybrid III mid-forearm. Figure 1 illustrates the details of the RAID.

EXPERIMENTAL SETUP

A side view of the test setup with the RAID is shown in Figure 2. The RAID was hung vertically down in front of the steering wheel and was allowed to rotate at the pivots in two directions as shown in the figure. It was possible to move the RAID in any direction to achieve the correct positioning with respect to the air bag module. The distance from the surface of the RAID to the plane of the steering wheel rim was changed according to test specifications. The steering wheel was rotated to achieve the desired test configuration (the orientation and position of the module tear seam with respect to the RAID). A load cell was located behind the steering wheel to measure reaction forces. The time of air bag cover opening was determined using break wires over the tear seam. A backstop with foam padding was used to stop the RAID after the air bag propelled it. The tests with the RAID were captured on film at 1000 frames per second by two high speed cameras for the front and side views.

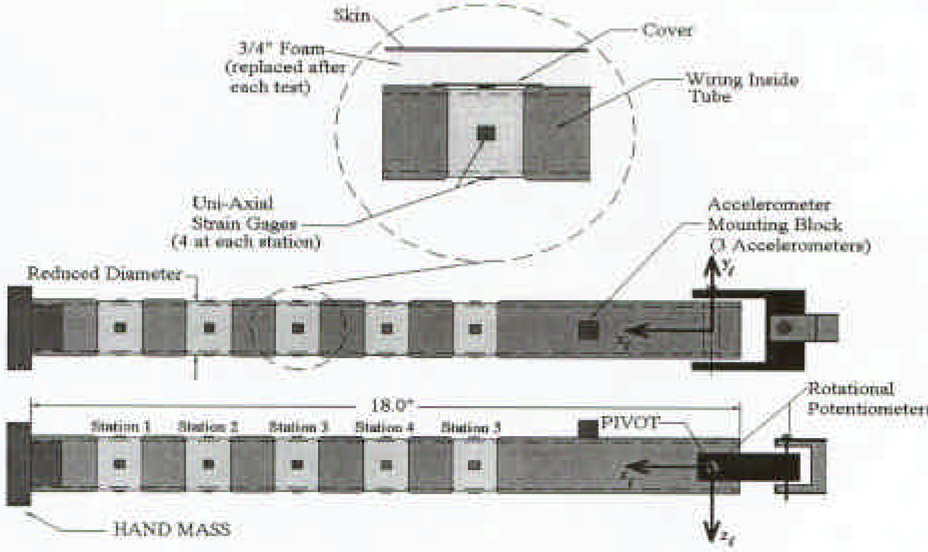

Figure 1: The Research Arm Injury Device

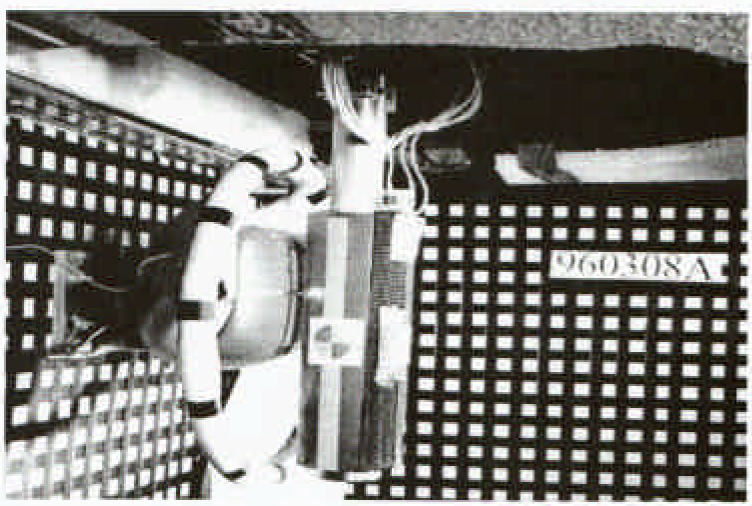

Figure 2: Side view of the RAID test setup.

SELECTION OF AIR BAGS

Six different air bag modules were selected for testing. The selection of the air bags was based in part upon the results from the NASS analysis and also upon tank test data. The System L was identified as a less aggressive bag from the NASS studies. The System J, System T, and the System P air bags were identified as less aggressive by the manufacturer. The System H and the System K were identified as aggressive air bags from the NASS studies as well as from tank test data. System H has a large heavy asymmetric module cover and System K has a very high tank pressure. These features make the Sytems H and K modules aggresssive in nature.

Table 1 presents various characteristics of these air bag modules. Figure 3 shows roughly scaled sketches of the different modules and covers. All modules except the System J air bag have an "H" tear pattern. The System J has an "I" tear pattern.

Table 1. Characteristics of air bag modules
(all measurements in centimeters)

Air Bag Characteristics	System H	System L	System K	System J
Diameter of steering wheel	38	38	38.7	39.7
Location of module plane wrt. To wheel	0.32 above	0.95 above	0.64 above	0.64 above
distance from top of rim to tear line	25.9	23.8	22.2	20.0
Vertical height of module	17.8	15.2	15.2	15.2
Horizontal width of module at seam	20.3	17.1	19.1	21.6
Distance from top of module to seam	13.8	9.1	7.8	10.8
Thickness of flaps	0.32	0.44	0.51	0.32
Vertical height of air bag	68.6	69.9	63.5	66.0
horizontal width of air bag	68.6	63.5	66.0	63.5
number of tethers	4	2	3	none
length of tethers	26.7	27.9	31.8	--

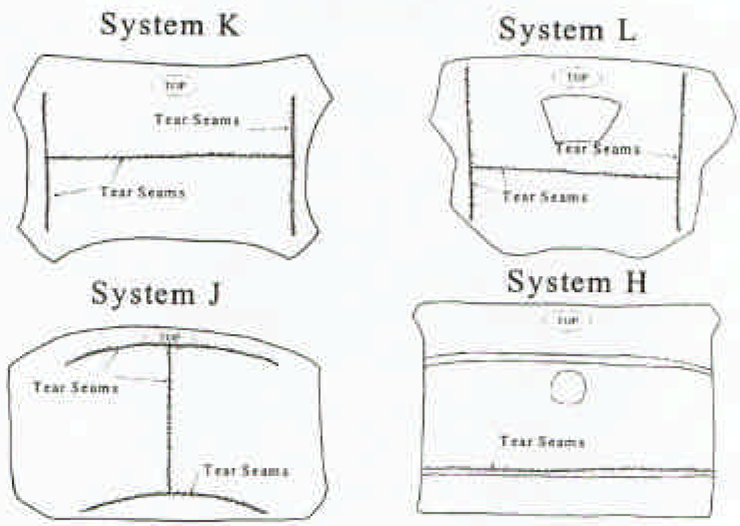

Figure 3: Sketches of air bag module covers indicating the tear patterns.

TEST CONFIGURATION

Thirty-four tests were conducted with the RAID using different air bag modules in different test configurations and distances from the plane of the steering wheel rim. A test configuration is defined as the orientation and position of the air bag module tear seam with respect to the RAID. After experimenting with various configurations, three main configurations, shown in Figure 4, were selected to compare air bag aggressivity.

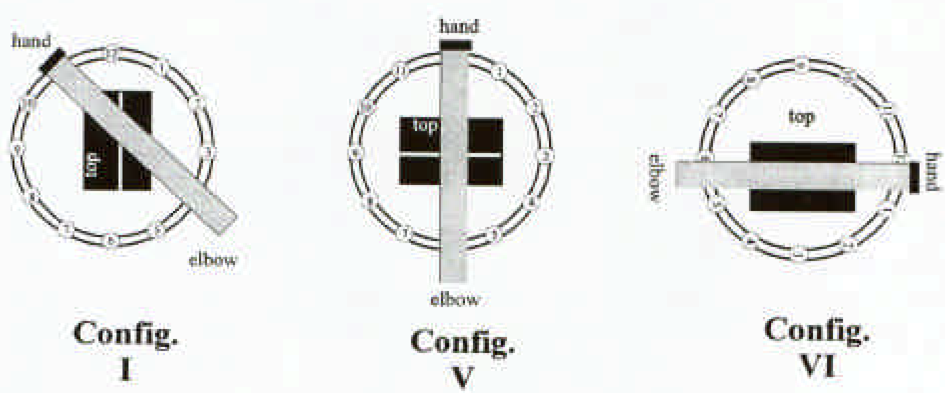

Figure 4: Three test configurations with the RAID.

Configuration I was designed to represent a person turning the wheel with their arm in front of the steering wheel. This configuration consists of a hand at 11 o'clock and an elbow at 4 o'clock, with the steering wheel rotated counter clockwise by 90 degrees from the neutral position.

Configurations V and VI were designed to study the most severe interaction of the arm with the air bag. Configuration V consists of the forearm located over the center of the module and oriented perpendicular to the tear seam of the module. Configuration VI consists of the forearm located over the center of the module and oriented parallel to the tear seam of the module. As a driver in a vehicle makes various maneuvers and adjustments, his or her arms are in continuous motion, so these configurations are thought to be plausible, although possibly less likely.

In addition to varying the test configurations, the distance of the RAID from the plane of the steering wheel rim was varied. Tests were conducted with the distance of the RAID from the plane of the steering wheel rim at 1.3 cm, 7.6 cm, and 12.7 cm.

TEST RESULTS

Results from static air bag deployment with the RAID suggested that the RAID was able to clearly distinguish between aggressive and less-aggressive air bags. The maximum moments, hand velocity, resultant acceleration, and steering column force were consistently higher for the aggressive air bags than the air bags identified as less-aggressive, as shown in Figures 5 to 8. The hand velocity was computed using the rotational potentiometer data.

Maximum moments ranging between 100 Nm and 650 Nm, and hand fling velocity ranging between 30 and 120 km/hr were measured on the RAID in these tests.

All the air bag module covers opened between 3 - 5 msec after the firing pulse. The maximum moments and accelerations occurred very early in the event - 5 to 20 msec (during the punch-out phase.) The maximum hand velocity occurred later when the RAID was propelled by the air bag and it was no longer in contact with the bag. The maximum velocity occurred between 30 - 40 msec. The maximum moments and velocity occurred earlier for the aggressive air bags than for the less-aggressive air bags.

When the initial distance of the RAID from the plane of the steering wheel rim was increased from 1.3 cm to 7.6 cm, the maximum moments, maximum accelerations, and maximum hand velocity decreased considerably. Further increasing the initial distance of the RAID from the air bag module to 12.7 cm did not change the maximum values of moments, accelerations, and velocity.

The maximum moment measured was located at station 4 which is 20 cm from the hand mass of the RAID. This station was approximately located at the air bag tear seam where the greatest effect of the punch out due to module cover opening was experienced. Figure 9 presents the peak moments at each station for the tests with the System L air bag in various configurations. As can be noted from Figure 9 the moments are lower for the tests where the initial distance of the RAID from the air bag module was increased so that the cover flaps did not impinge on it during the punch out phase.

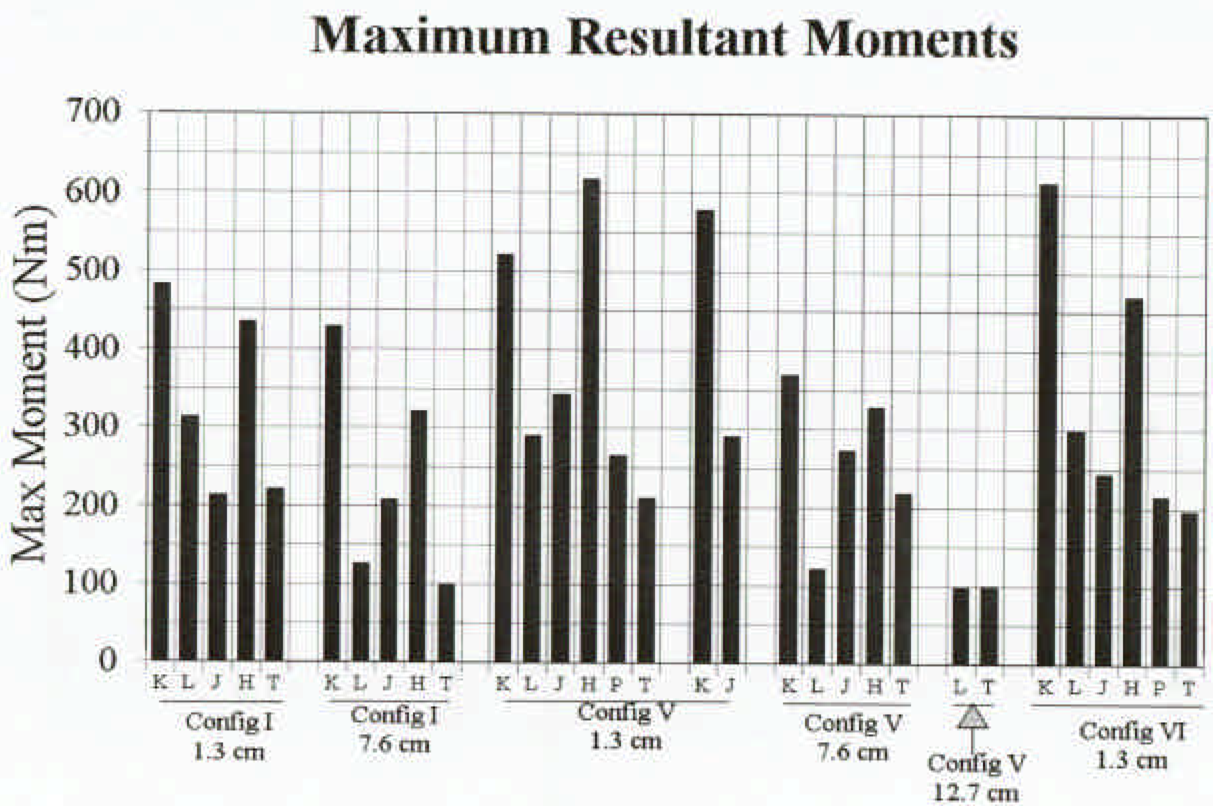

Figure 5: Maximum resultant moment by air bag module and test configuration. K- System K, H-System H, L-System L, J-System J, P - System P, and T - System T. I, V, VI, indicates the test configuration.

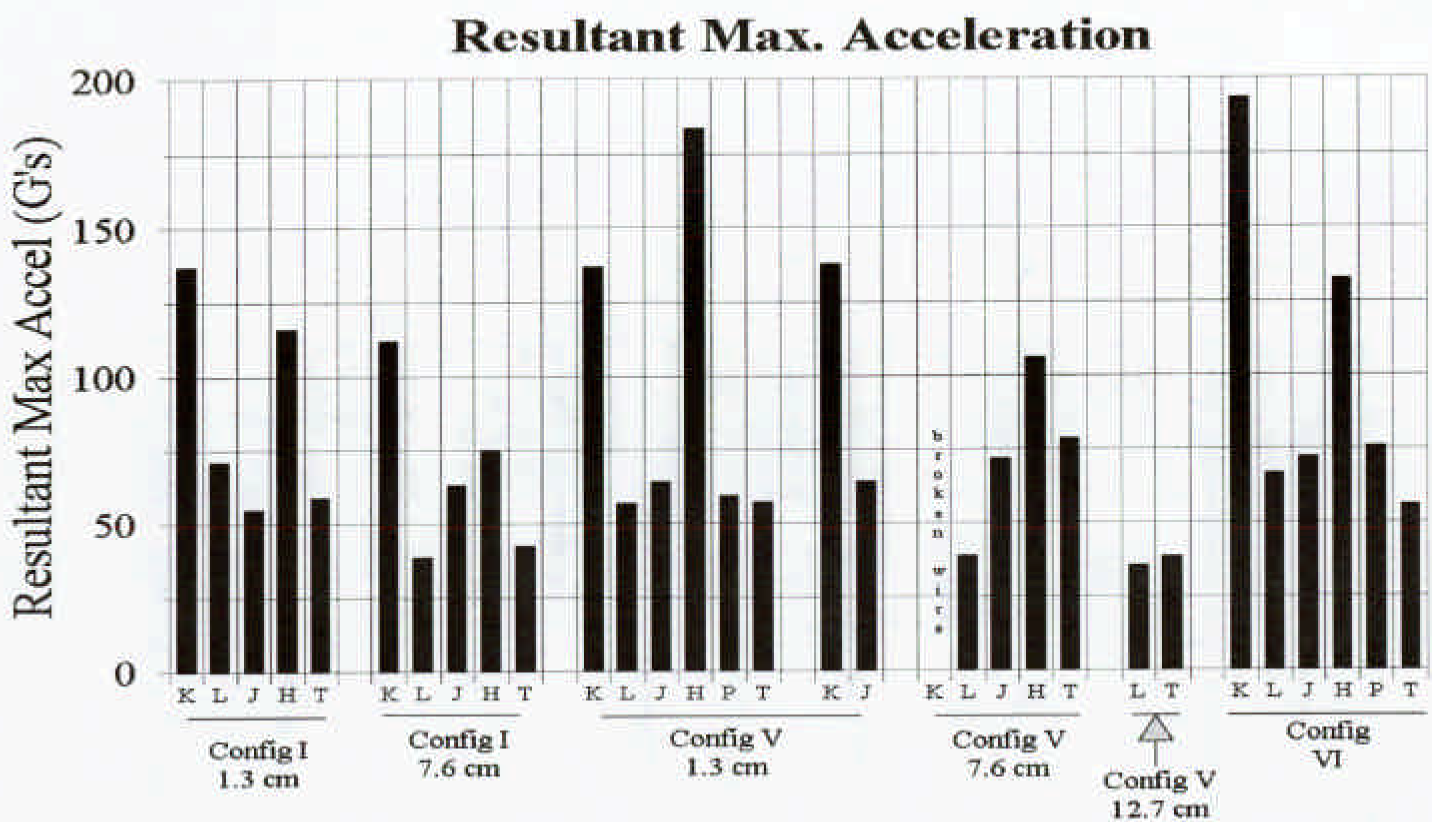

Figure 6: Maximum resultant acceleration by air bag module and test configuration. K- System K, H-System H, L-System L, J-System J, P - System P, and T - System T. I, V, VI, indicates the test configuration.

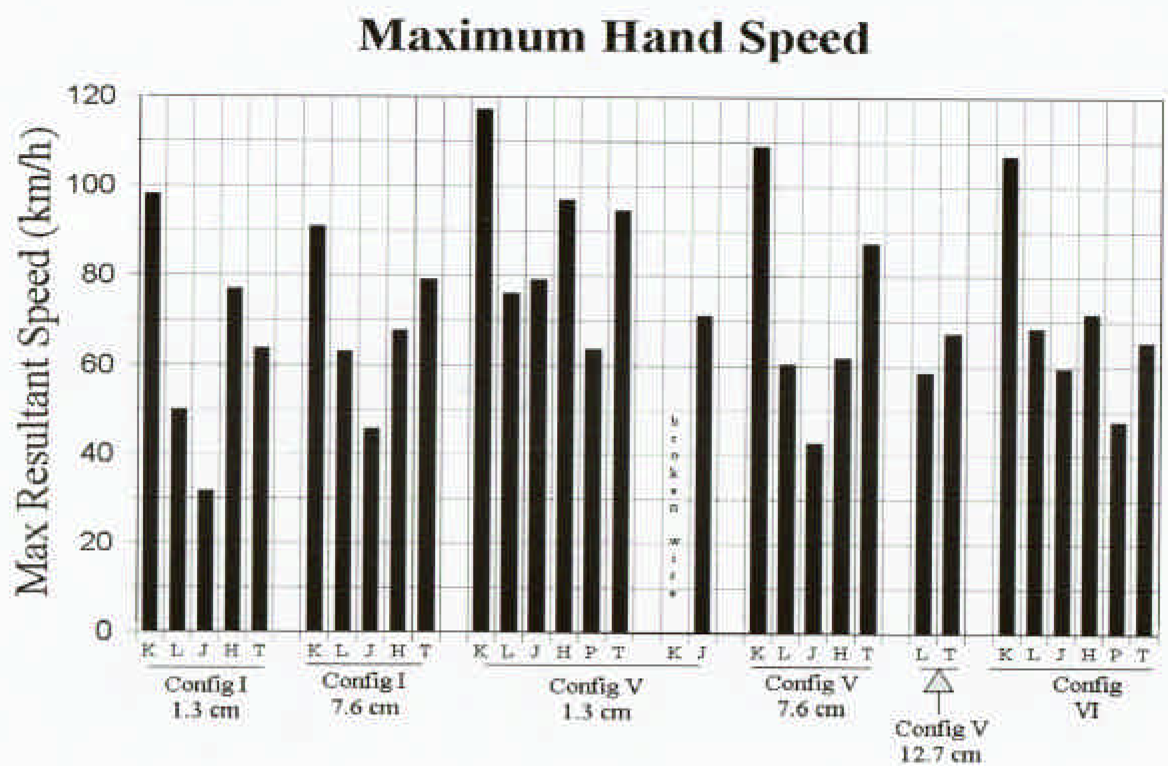

Figure 7: Maximum hand velocity by air bag module and test configuraton. K- System K, H-System H, L-System L, J-System J, P - System P, and T - System T. I, V, VI, indicates the test configuration.

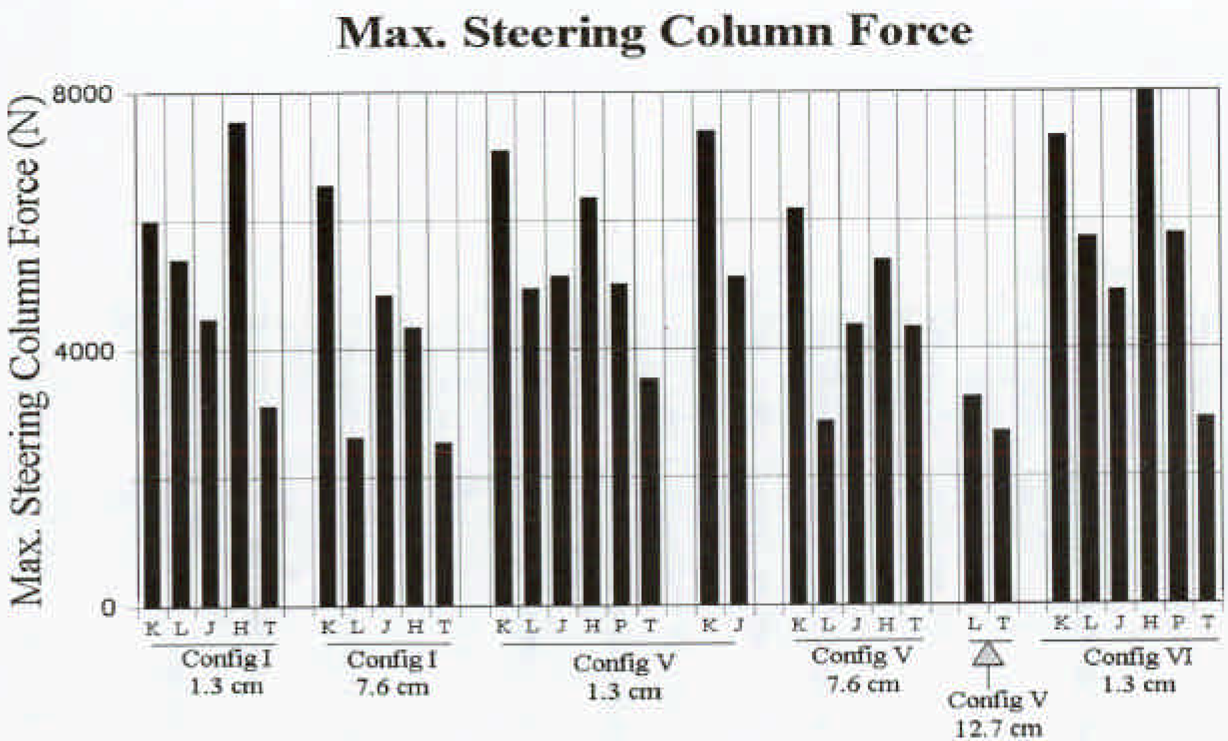

Figure 8: Maximum steering column loads by air bag module and test configuraton. K- System K, H-System H, L-System L, J-System J, P - System P, and T - System T. I, V, VI, indicates the test configuration.

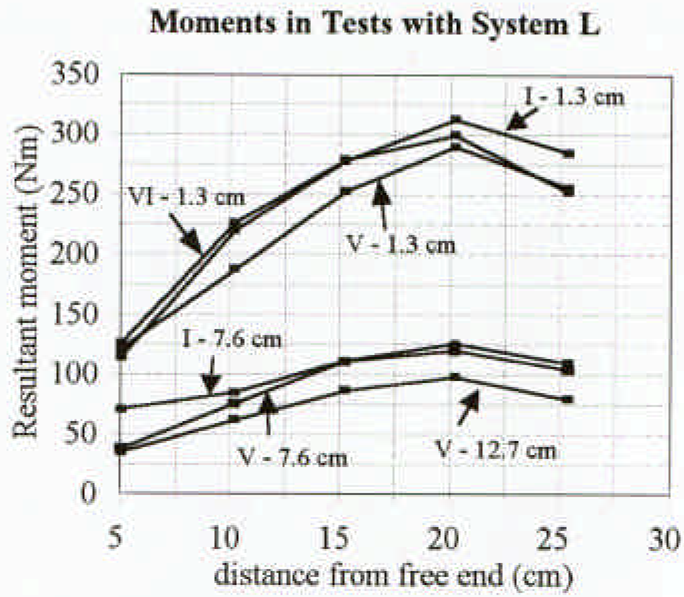

Figure 9: Peak moments for each station in tests with the System L air bag.

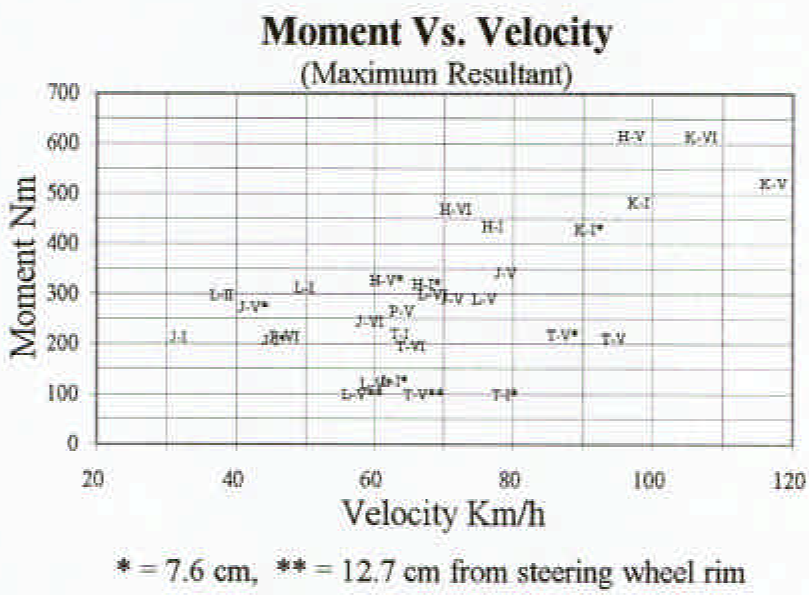

Figure 10: Maximum moment versus maximum velocity plots. K- System K, H-System H, L-System L, J-System J, P - System P, and T - System T. I, V, VI, indicates the test configuration.

Two major parameters measured on the RAID were identified to clearly distinguish between the aggressive and less-aggressive air bags. They are the maximum resultant moment and the maximum hand velocity. Figure 10 presents the maximum moment versus maximum hand velocity for all the tests in Configurations I, V, and VI. This figure suggests that the aggressive air bags imparted a maximum moment on the RAID above 300 Nm and a hand fling velocity above 75 km/h. In general, the maximum moments and hand velocity decreased when the initial distance between the air bag module cover and the RAID was increased.

The orientation and the distance of the arm with respect to the air bag module were identified as critical to the test setup. Of all the test configurations examined, configuration V was most severe. Repeatability tests were conducted with the System J and System K air bags. Good repeatability in the acceleration, moments, and rotation signals were evident.

PROVISIONAL REFERENCE VALUE FOR THE FRACTURE TOLERANCE OF THE HUMAN FOREARM

The relative severity of the various air bag modules can be determined from the RAID tests. However, in order to ascertain whether a particular air bag module would cause injury to the forearm, the fracture tolerance of the human forearm had to be determined.

As a first step, the fracture tolerance of the human forearm was estimated from static 3-point bending test data of isolated bones reported by Yamada [2] and Melvin [3]. Melvin reported the breaking load in bending of the radius and ulna of male and female human post-mortem specimens. Assuming the bending strength of the radius and ulna to be additive and assuming a dynamic factor of 1.5 as suggested by Melvin, the dynamic fracture tolerance of the human forearm was estimated to be 115 Nm for male specimens and 90 Nm for female specimens.

Figure 5 suggests that all the air bags tested produced bending moments on the RAID which exceeded the estimated fracture strength of the forearm. The RAID was designed as a simple investigative tool and not necessarily a biofidelic device. Hence, the responses measured on the RAID may not represent human response. In order to identify whether a certain air bag would injure the human forearm, it would be necessary to scale the RAID response to represent that of a human forearm.

CONCLUSIONS

A mechanical device called the Research Arm Injury Device was developed to study forearm-air bag interactions and to assess the relative aggressivity of various air bag sytems. Preliminary testing with the RAID suggested that this device was able to distinguish between aggressive and less-aggressive air bags with reasonable accuracy. Maximum moments ranging between 100 Nm and 650 Nm, and hand fling velocity ranging between 30 and 120 km/hr were measured on the RAID in these tests.

The orientation of the arm with respect to the air bag module and the distance of the arm from the air bag module were identified as critical to the test setup. The most severe case occurred when the RAID was directly over the center of the module and the tear seam was perpendicular to the RAID. When the initial distance between the RAID and the air bag module was increased, the maximum moment, acceleration, steering column loads, and hand velocity decreased.

The punch out phase when the deploying air bag/module cover first interacts with the RAID during its deployment was when the RAID experienced maximum moments and velocities. The punch-out phase is therefore the most critical period of air bag deployment for causing trauma to the upper extremities.

ACKNOWLEDGMENT

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[3] Melvin, J., Evans, F. G., "The Biomechanics of Trauma," Chapter 21, Edited by Nahum, A. M., Melvin, J., Appleton-Century-Crofts/Norwalk, Connecticut.

DISCUSSION

PAPER: **Study Of Forearm - Airbag Interaction Using The Research Arm Injury Device (RAID)**

PRESENTER: Mitchell Oslon, Conrad Technologies, Inc.

QUESTION: Guy Nusholtz, Chrysler Corporation

How did you eliminate the need for having a grip associated with the hand? Have you done anything to show that that's not very significant?

ANSWER: We didn't try to eliminate the need for a grip. This device was mainly used to measure the relative severity of airbags and we're using an arm type device but we were not trying to take into account the grip of the arm. So, that was not a factor in our testing.

Q: OK. Thank you.